A MODELING METHODOLOGY TO SUPPORT EVALUATION OF PUBLIC HEALTH IMPACTS OF AIR POLLUTION REDUCTION PROGRAMS

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Abstract

Environmental public health protection requires a good understanding of the types and locations of pollutant emissions of health concern and their relationship to environmental public health indicators. Therefore, it is necessary to develop the methodologies, data sources, and tools for assessing the public health impact of air pollution reduction programs, also referred to as accountability analysis. Since air quality models are among the main tools that can be used to evaluate the impacts from emissions changes, either due to growth or implementation of source control strategies, these approaches play a vital role in most air accountability studies.

In this study, we present a modeling methodology to estimate concentrations for multiple pollutants that include both local features (hot spots) and regional transport. The local impacts from mobile sources and significant stationary sources are estimated using a dispersion model (AERMOD). These local details are combined with regional background estimates computed by a photochemical grid model (CMAQ) in a "hybrid" approach to derive total concentrations required for the subsequent human exposure analysis.

We demonstrate an application of this methodology in New Haven, Connecticut. The city of New Haven has implemented a comprehensive Clean Air Initiative, which includes a number of federally mandated and voluntary air pollution programs. This project is a collaborative effort with state and local agencies including government, academia, and the New Haven community, to apply and evaluate air quality and human exposure models that can be used with health data and to assess the feasibility of using this information to conduct an air accountability study. Although this study is based in one city, the methodologies developed through this project can have broad application to other areas within the United States and internationally.

1. INTRODUCTION

Air quality has improved substantially in the United States in recent decades, in large part due to increasingly stringent federal and state air quality regulations. While many studies have documented links between better air quality and improvements in a variety of human health metrics, direct evidence is lacking about the extent to which specific control measures have improved health. Over the past decade, various epidemiological studies have examined the relationships between acute and chronic health outcomes and measured ambient particulate matter, ozone and other co-pollutant concentrations. In the context of air pollution health effects, results from recent epidemiological studies indicate the importance of determining the key sources and constituents of indoor, outdoor pollution, and personal exposures to PM, ozone and other air pollutants. However, understanding the magnitude and nature of human exposure is clearly the first step in assessing the occurrence of adverse effects that could follow upon contact with environmental pollutants. One of the ways to access the human exposure is through the use of exposure models such as EPA's Hazardous Air Pollutant Exposure Model (HAPEM), the Air Pollutant Exposure Model (APEX), or Stochastic Human Exposure and Dose Simulation (SHEDS).

Since predicted concentrations from air quality models are key drivers for human exposure models, it is essential to improve the accuracy and precision of spatial and temporal characterization of results from these models. However, complex interactions between interventions over time can make it difficult to isolate the environmental impacts and associated health effects of any one regulation. For example, a regulatory action may have varying effects on emissions depending upon compliance and the real-world effectiveness of the interventions applied. Often, the connection between emissions and ambient air quality depends on complex atmospheric and chemical transformations. Environmental public health protection requires a good understanding of the types and locations of pollutant emissions of health concern and their relationship to environmental public health indicators. Therefore, it is necessary to develop the methodologies, data sources, and tools for assessing the public health impact of air pollution reduction programs, and accountability analysis. Since air quality models are the principal predictive tool for assessing the impacts of potential emissions control strategies on future-year concentrations, we describe here a modelling approach to support air accountability studies.

2. AIR QUALITY MODELING APPROACH

Environmental health studies require detailed information on air quality. Therefore, air quality modelling should include local-scale features, long-range transport, and photochemistry to provide the best estimates of air concentrations. There are several available modelling approaches capable of assessing pollutant concentration gradients at a fine resolution (Touma et. al., 2006) and these can be categorized into two major types of air quality models: source-based dispersion models and Eulerian grid-based chemical transport models. Chemical transport models, such as the Community Multi-scale Air Quality (CMAQ, Byun and Schere, 2006), are used to simulate the transport and formation of ozone, acid rain, particulate matter (PM) and other pollutants formed by chemical reactions among precursor species that are emitted from hundreds or thousands of emission sources. Such models may be set up to apply to a wide range of scales ranging from global to urban. However, regional-scale grid-based models can address photochemistry effects, but not local-level gradients. CMAQ provides volume-average, hourly concentration values for each grid cell in the modelling domain. Emissions are assumed to be instantaneously well-mixed.

While grid-models are the model platform of choice for simulation of chemically-reactive airborne pollutants, source-based dispersion models such as AERMOD (Cimorelli et. al., 2005) that have been developed to simulate pollutant concentrations within a few hundred meters or a few kilometers from the source are typically used for local scales. These models generally do not take into account atmospheric chemical reactions or they do so using simplified representations such as first-order pollutant decay. They provide detailed resolution of the spatial variations in hourly-average concentrations. It would be desirable to combine the capabilities of grid-models and dispersion models into one model, but this is a yet evolving area of research and development. One option is a hybrid approach (Isakov et. al., 2007), where a regional grid model and a local plume model are run independently. To illustrate how air quality models can be used to provide inputs to human exposure models, we focus on a 20 by 20 km area encompassing New Haven, Connecticut that includes many stationary sources emitting toxic pollutants and several major roadways as indicated in Figure 1. The city of New Haven, with population of approximately 125,000, is a recipient of one of EPA's nationally funded Community Air Toxics projects. Through this project, New Haven has implemented a comprehensive Clean Air Initiative, which includes a number of voluntary air pollution programs. Along with local and state efforts, there are also several Federal regulations that have either recently been or soon will be implemented (e.g., Clean Air Interstate Rule). This project presents an opportunity to assess the feasibility of using air quality and human exposure models that can be used with health data to conduct an air accountability study.

Resolving fine scale pollutant gradients to identify local concentration hot spots from both stationary and mobile sources is critical for exposure assessments. For example, individuals who spend more time near busy highways are likely to be exposed to higher levels of air pollution. To account for this near-road exposure we modelled ambient air quality concentrations for multiple pollutants resulting from roadway emissions. There are multiple modelling techniques to simulate near-road dispersion from mobile sources (Borrego et. al., 2006, Cook et. al., 2006). In this study, we used the AERMOD dispersion model which treats individual road links as area sources to simulate hourly concentrations of various pollutants near the road. AERMOD also simulates near-source impacts from stationary sources. Contributions to photochemical interactions are provided as a background concentration level from CMAQ, a regional grid model.

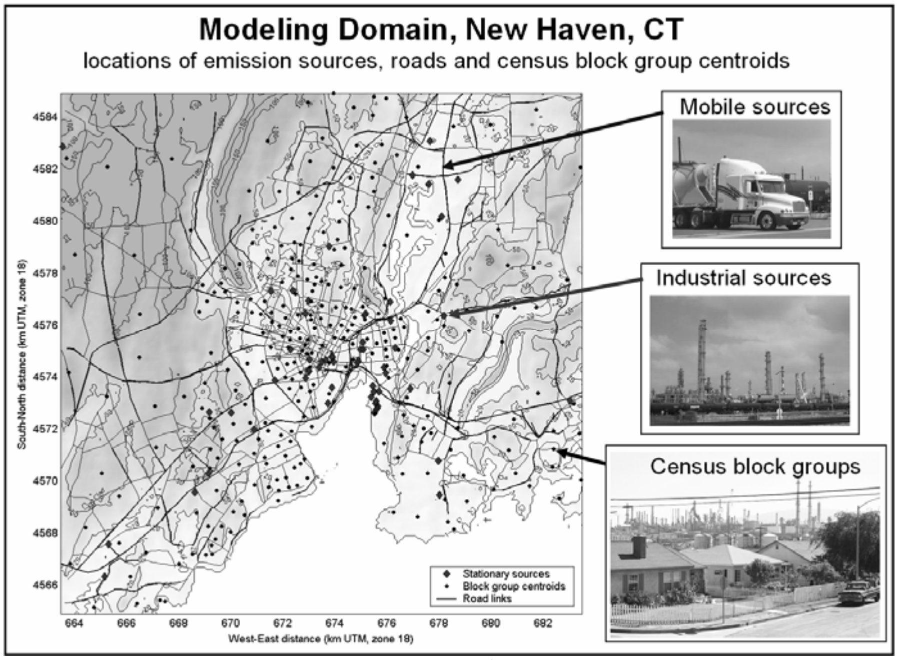

Figure 1. Modelling domain showing locations of emission sources and model receptors.

A hybrid approach (Isakov et. al., 2007) is a logical and efficient way to combine regional grid and local plume models. Results of both model simulations are combined to provide the total ambient air pollutant concentrations. The hybrid approach uses the appropriate modelling tools to describe different types of sources, making its application computationally efficient. Furthermore, since local dispersion models are not resource intensive, this methodology allows the study of local concentration variability due to changes in several model inputs and physical parameters, helping gain confidence in the simulation results by encompassing a range of model outcomes. This constitutes a clear advantage of the hybrid approach, since performing a local concentration variability estimation using a nested grid model alone would be an impractical task, especially over larger urban areas. A schematic of the hybrid approach is shown in Figure 2, where the CMAQ model was used to estimate regional background concentrations and AERMOD was used to estimate local-scale details for stationary and mobile sources.

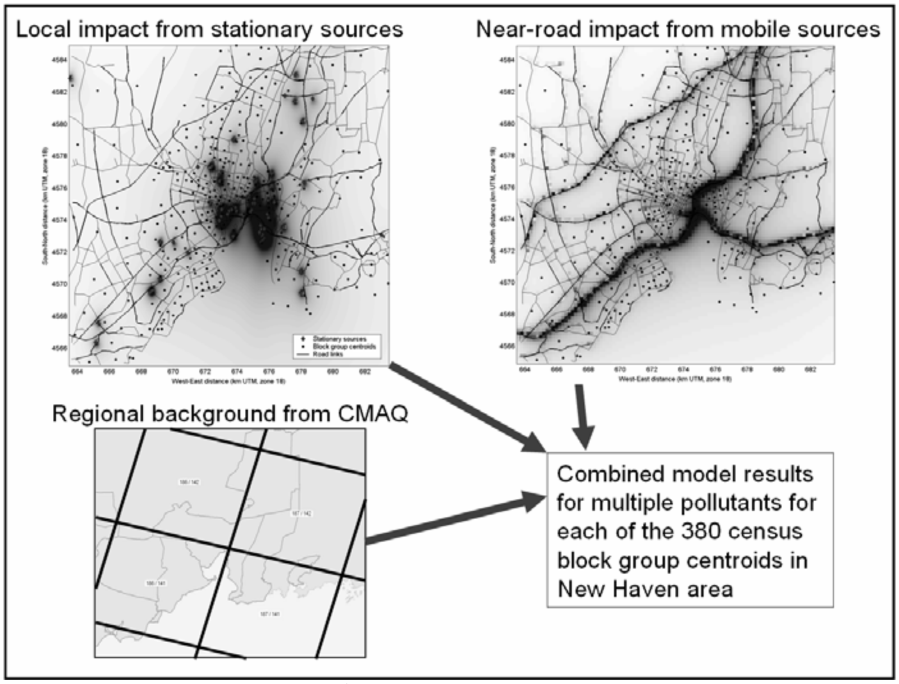

Figure 2. Application of the hybrid approach in New Haven, Connecticut.

In this study, CMAQ was used to simulate ambient concentrations of several air toxics (Lueken et. al., 2006). The CMAQ modeling system was run for an annual period in a nested mode at 36 and 12 km horizontal grid dimensions using the 1999 National Emission Inventory and meteorological outputs from 2001 using the MM5 meteorological model. The CMAQ results were extracted for the New Haven modelling domain to provide regional background concentration values. This regional background was combined with local concentrations predicted by the AERMOD dispersion model. The application of this hybrid approach is illustrated in Figure 3 which displays modelled annual average outdoor carbon monoxide concentrations in New Haven, Connecticut. Predicted CMAQ concentrations at 12 by 12 km resolution are combined with estimates at 200m receptor resolution from AERMOD.

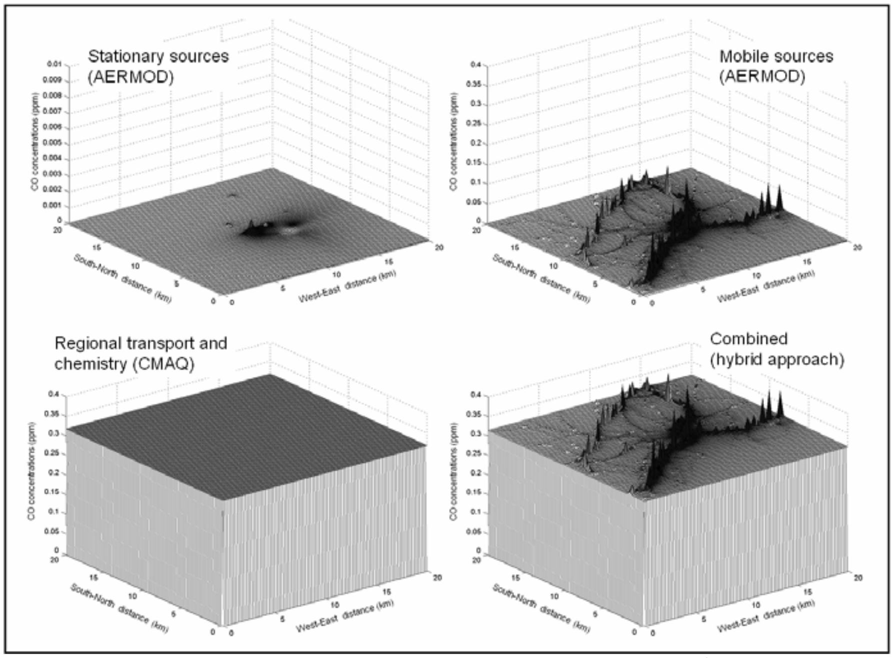

Figure 3. Annual average CO concentrations in New Haven, Connecticut: (a) impact of stationary sources; (b) impact of mobile sources; (c) regional background; (d) combined concentrations using hybrid approach.

3. MODELING APPROACH FOR ACCOUNTABILITY STUDIES

The methodologies developed under this project can be applied to future projects in other areas to simulate air quality impacts for various controls scenarios. For example: 1) what happens if emissions from some specific stationary sources are reduced by “x” percent? 2) what happens if emissions from mobile sources could be reduced by “y” percent? 3) what is the impact of local controls? 4) what is the impact of regional/national controls resulting in reduction of regional background? Figure 4 provides a hypothetical example of the relative impacts of various control strategies on ambient concentrations. These examples include: reducing emissions from mobile sources, controlling emissions from stationary sources, and reducing impact of the regional background. This example helps determine which control options are most effective in reducing ambient concentrations. In order to link these air quality estimates to health effects associated with human exposures to environmental pollutants, we will use exposure modelling. When combined with exposure models, the control strategies can be assessed to optimize the impacted population, or population subset, such as children, people with respiratory problems, etc. In this study, we are evaluating alternative techniques for estimating cumulative exposures to selected air toxics, PM, and ozone using probabilistic cumulative exposure models: HAPEM 6 and SHEDS-Air Toxics, time-series based models, using human activity pattern data, modeled/measured concentrations, and exposure factors.

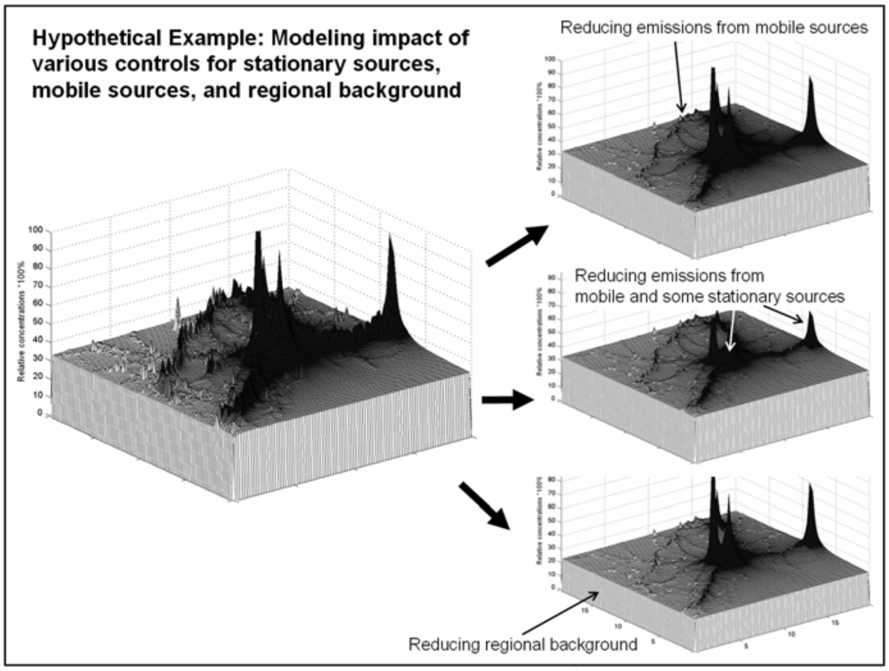

Figure 4. Example of modelling application to investigate the effect of various control strategies.

4. SUMMARY

At the present, most Federal and State air quality implementation plans rely heavily on ambient modeling study results for targeting emissions reductions. However, the complexity in the spatial and microenvironmental variation of exposures among the different population subgroups, especially in the context inter- and intra-urban analysis of air pollution health effects, could pose several challenges. Thus, integrated air quality – human exposure modeling provides the means to evaluate the potential health risks from air pollution exposures and the basis to determine optimum risk management strategies, while considering scientific, social and economic factors. Ideally, emission control strategies not only aim at reducing the emissions from principal sources of targeted pollutants but also to identify those sources and microenvironments that contribute to greatest portion of personal or population exposures. Recent advances in exposure modeling tools and better information on time-activity, commuting and exposure factors data provide unique opportunities for improving the assignment of exposures during the course of future accountability and community health studies. Moreover, the combination of sophisticated air quality and exposure models will improve the accuracy of present air quality and exposure forecasts, and help us better quantify the health and economic benefits of emissions reductions programs, as part of air accountability studies.

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